

# Environmental technology assessment of natural gas compared to biogas

Ola Eriksson  
*University of Gävle*  
*Sweden*

## 1. Introduction

The aim of this chapter is to bring about information on how the renewable competitor to natural gas – biogas – is produced, and to make a comparison of natural gas and biogas from primarily an environmental point of view in a life cycle perspective.

### 1.1 Historical background

In a historical perspective, biogas has been produced since the second half of the 19<sup>th</sup> century. India and China were among the pioneering countries, where biogas produced from manure and kitchen waste for long time has been used as a fuel for gas cookers and lamps. In Sweden, biogas has been produced at municipal waste water treatment plants since the 1960's. The primary incentive was to reduce sludge volumes. However, the oil crises of the 1970's rang alarm bells, leading to research and development of biogas techniques, and construction of new plants in order to reduce environmental problems and dependency on oil. (Swedish Biogas Association, 2004)

Industry was the first to act: sugar refineries and pulp mills started to use anaerobic digestion for waste water purification in the 1970's and 1980's. At this time, several smaller farm-sized plants were also constructed for anaerobic digestion of manure. During the 1980's, several landfill plants started to collect and utilise biogas produced in their treatment areas, an activity that expanded quickly during the 1990's. Several new biogas plants have been constructed since the mid-1990's to digest food industry and slaughterhouse wastes, and kitchen wastes from households and restaurants. (Swedish Biogas Association, 2004)

### 1.2 Properties of biogas

Biogas consists of 45-85 % methane ( $\text{CH}_4$ ) and 15-45 % carbon dioxide ( $\text{CO}_2$ ), with the exact proportions depending on the production conditions and processing techniques. In addition, hydrogen sulphide ( $\text{H}_2\text{S}$ ), ammonia ( $\text{NH}_3$ ) and nitrogen gas ( $\text{N}_2$ ) may be present in small amounts. Biogas is normally saturated with water vapour.

Artificially produced methane, for example from wood products by a process called thermal gasification, is sometimes confusingly called biogas. This is also a renewable source of methane. The amount or volume of biogas is normally expressed in 'normal cubic meters' ( $\text{Nm}^3$ ). This is the volume of gas at 0 °C and atmospheric pressure. The energy value is expressed in joule (J) or watt hours (Wh). Pure methane has an energy value of 9.81 kWh/ $\text{Nm}^3$  (9810 Wh/ $\text{Nm}^3$ ). The energy value of biogas varies between 4.5 and 8.5 kWh/ $\text{Nm}^3$ , depending on the relative amounts of methane, carbon dioxide and other gases present. Thus, if biogas comprises 60 % methane, the energy content is appr. 6.0 kWh/ $\text{Nm}^3$ . Energy content of biogas compared to other fuels are displayed in Figure 1.

1 $\text{Nm}^3$ biogas (97 % methane) = 9.67 kWh
1 $\text{Nm}^3$ natural gas = 11.0 kWh
1 litre petrol = 9.06 kWh
1 litre diesel = 9.8 kWh
1 litre E85 = 6.6 kWh
1 $\text{Nm}^3$ biogas is equivalent to appr. 1.1 litres of petrol.
1 $\text{Nm}^3$ natural gas is equivalent to appr. 1.2 litres petrol.

Fig. 1. Energy content of different fuels. Source: [www.preem.se](http://www.preem.se) (petrol, diesel, E85), [www.swedegas.se](http://www.swedegas.se) (natural gas)

Both methane and carbon dioxide are odourless. If raw biogas smells, it is usually due to the presence of sulphur compounds. Biogas may ignite at concentrations of about 5-20 % in air, depending on the methane concentration. Methane is lighter than air, whereas carbon dioxide is heavier. This is considered to be advantageous from a safety point of view, since methane easily rises and is quickly diluted by the air. (Swedish Biogas Association, 2004)

### 1.3 Biogas today and in the future

The global production of biogas is hard to estimate, whereas data on European level is more reliable. Statistics for production and use of biogas is published by EurObserver and Eurostat.

European production of primary energy from biogas reached 7.5 million toe in 2008, i.e. a 4.4 % increase on 2007 (an addition of 318.6 ktOE). Landfill biogas accounted for 38.7 % of the total followed by 13.2 % from waste treatment plants (urban and industrial). The other sources, mainly agricultural biogas units (combining liquid manure with substandard cereals, for instance), and also centralised co-digestion units (liquid manure with other organic matter and/or animal waste) and solid household waste methanisation units, accounted for almost half Europe's biogas production, i.e. 48.2 % in 2008. (Euroobserver, 2009)

Figure 2 illustrates the primary energy production of biogas in Europe in 2007. Unfortunately such map has not been found for 2008 figures. It should be noted that primary energy production estimate of 2008 differs considerably from the estimate for 2007 because of the very significant consolidation in the German statistics. The 2007 data has been consolidated to 3,659.1 ktOE compared to the previous estimate of 2,383.1 ktOE. This major consolidation is justified by taking into consideration from 2008 self-producer heat production, which is essentially the heat produced by farm installations. (Euroobserver, 2009)

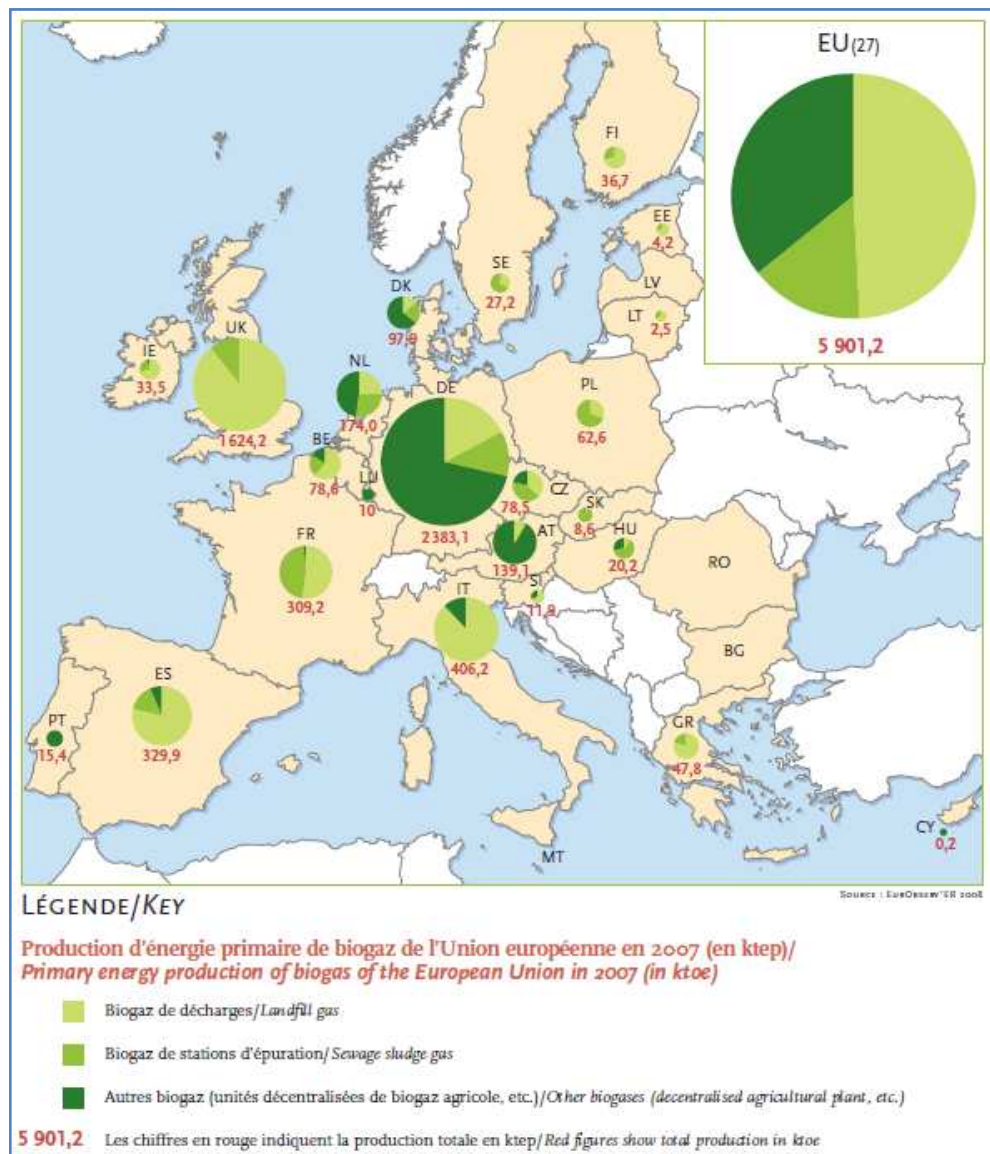


Fig. 2. Estimation of primary energy production of biogas in Europe 2007. Source: Eurobarometer, 2008

Electricity production increased in 2008 at a slightly slower rate than that of primary energy production that is up 3.9 % over 2007, or a total of almost 20 TWh. Cogeneration plants generated 18.3 % or nearly 3.7 TWh of this total production. (Eurobarometer, 2009)

In order to illustrate the offset for biogas in Europe figures from 2005 have been used as figures from 2008 only covers generated electricity. In 2005 recovered biogas was used for

electricity (13 TWh), heat (8 TWh) and vehicle fuel (0.1 TWh). The majority of the heat- and power generation comes from Germany and Great Britain whereas almost all vehicle fuel was generated in Sweden. Figure 3 illustrates the distribution of energy from biogas production in each European country. (AvfallSverige, 2008)

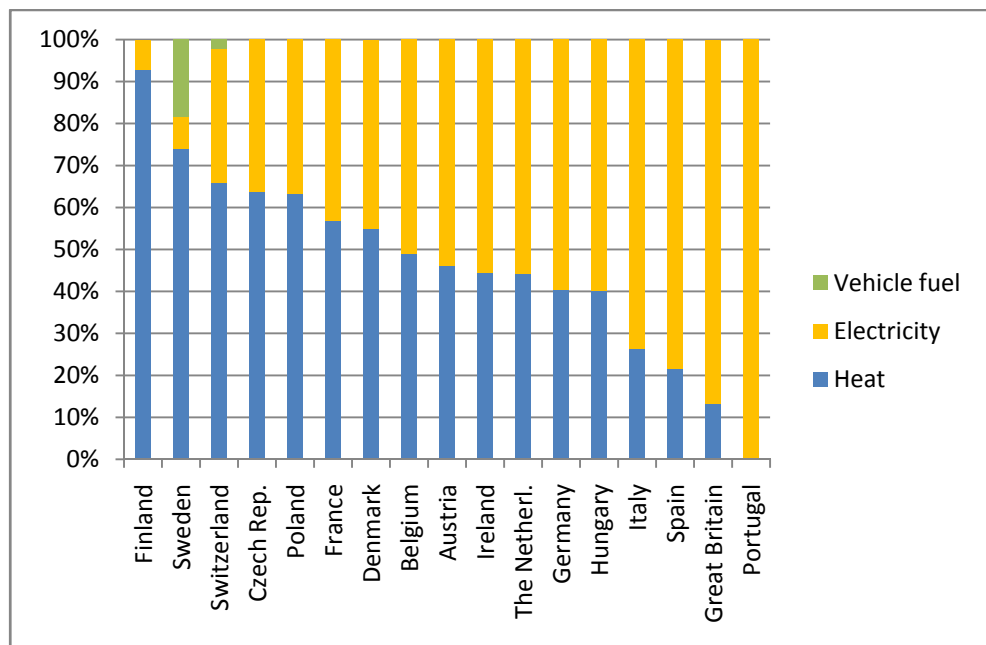


Fig. 3. Distribution for the generation of electricity, heat and vehicle fuel from landfill gas and biogas in each country in 2005. Sources: Switzerland (BFE, 2006), Sweden (Energimyndigheten, 2007), others (Euroobserver, 2007)

What are the trends for 2010? Present growth rates are too low to meet the European Commission's White Paper targets (15 Mtoe in 2010). EurObserv'ER puts production at 8.2 Mtoe in 2010 (mean annual growth rate rising by 4.4% in 2009 and 2010). This production would amount to 5.5% of the European Commission's "Biomass Action Plan" set at 149 Mtoe for 2010. The major price hike in agricultural raw materials should limit the growth of agricultural biogas production, which is the driving force of biogas growth in Europe, to below previous forecast levels.

#### 1.4 General comparison of natural gas, biogas and landfill gas

The composition of biogas depends on a number of factors such as the process design and the nature of the substrate that is digested. A special feature of gas produced at landfills is that it includes nitrogen. The table below lists the typical properties of biogas from landfills, digesters and a comparison with average values for Danish natural gas for 2005. (SGC, 2007)

Property	Unit	Landfill gas	Biogas	Natural gas
Calorific value, lower	MJ/Nm <sup>3</sup>	16	23	40
	kWh/Nm <sup>3</sup>	4.4	6.5	11
	MJ/kg	12.3	20.2	48
Density	kg/Nm <sup>3</sup>	1.3	1.2	0.83
Wobbe index, upper	MJ/Nm <sup>3</sup>	18	27	55
Methane number		>130	>135	72
Methane	vol-%	45	65	89
Methane, range	vol-%	35-65	60-70	-
Long-chain hydrocarbons	vol-%	0	0	10
Hydrogen	vol-%	0-3	0	0
Carbon monoxide	vol-%	0	0	0
Carbon dioxide	vol-%	40	35	0.9
Carbon dioxide, range	vol-%	15-50	30-40	-
Nitrogen	vol-%	15	0.2	0.3
Nitrogen, range	vol-%	5-40	-	-
Oxygen	vol-%	1	0	0
Oxygen, range	vol-%	0-5	-	-
Hydrogen sulphide	ppm	<100	<500	3
Hydrogen sulphide, range	ppm	0-100	0-4000	1-8
Ammonia	ppm	5	100	0
Total chlorine as Cl <sup>-</sup>	mg/Nm <sup>3</sup>	20-200	0-5	0

Table 1. Comparison of properties for landfill gas, biogas and natural gas.

Sources: SGC, 2005; Energinet, 2005

The major difference is of course that natural gas is methane with fossil origin. Emissions of CO<sub>2</sub> from natural gas contributes to global warming, CO<sub>2</sub> from landfill gas and biogas does not. Natural gas is however a less polluting fuel than other fossil fuels, like coal and oil. Especially emissions of greenhouse gases at combustion are lower per unit energy than for coal and oil, but also NO<sub>x</sub> emissions are often lower.

### 1.5 Problem

Natural gas and biogas is essentially the same type of gas, methane. In LCA literature natural gas is compared to other fossil fuels like coal and oil or maybe biomass, e.g. Eriksson et al, 2007. Biogas on the other hand is mostly compared to petrol or diesel, and possibly with system enlargement also with production and use of chemical fertiliser as the biogas process also produces valuable organic fertiliser. Biogas is also compared to other fossil fuels when electricity is generated.

So far, there seem to be few comparisons of natural gas and biogas with respect to environmental performance. A fuel wise comparison (pre combustion) of the two is therefore interesting, regardless of type of energy recovery. Another problem is lack of generic data on biogas as fuel. LCA databases consist of several datasets for natural gas but none or few for biogas.

## 2. Method and tools

To be able to compare natural gas and biogas, a literature survey has been made for papers on LCA of at least one of the two fuels. Of specific interest are studies showing the contribution from each step of the life cycle from extraction of raw materials to at least gas ready to use, or possibly also combustion with energy recovery as electricity, heat and vehicle fuel. If possible, data on specific emissions have been tracked down, or at least results from impact assessment using a given method.

When performing this meta-study it comes clear that there are many factors or parameters that affect the outcome of the assessment. They are well familiar in LCA as system boundaries, methods for allocation, choice of energy sources etc. The inventory of interesting studies has thus resulted in five papers which have been used to (1) guide the reader of the LCA in what is the environmental impact from each step of the fuel production process and (2) identify crucial factors in LCA of these fuels. The latter is further elaborated in the discussion part.

### 2.1 Goal and scope definition

The basic idea was to perform the review with a functional unit of 1 MJ of methane gas pre combustion. It is however hard to ignore the fact that the emissions of CO<sub>2</sub> has to be handled in separate ways for the two gases. Therefore utilisation of the methane to end user products as electricity and vehicle fuel has been presented also.

### 2.2 Inventory analysis and impact assessment

Following studies have been collected:

1. Environmental systems analysis of biogas systems – Part I: Fuel-cycle emissions by Börjesson & Berglund (2006). The study comprises biogas from different substrates. The functional unit is 1 MJ of biogas. Emissions are presented for each step of the process. No impact assessment is made.
2. A life cycle impact of the natural gas in the energy sector in Romania by Dinca et al (2006). The study comprises natural gas with a mix of gas from Russia and Romania. The functional unit is 100 GJ of thermal energy. Emissions are presented for each step of the process. Impact assessment is made using CML 1992.
3. Natural gas and the environmental results of life cycle assessment by Riva et al (2006). The study comprises natural gas from different countries and plants. The functional unit is 1 kWh of electricity. Emissions are not presented for each step of the process. Impact assessment is made for GWP and AP using defined weighting factors with no reference.
4. Life Cycle Assessment of biogas production by monofermentation of energy crops and injection to the natural gas grid by Jury et al (2010). The study comprises both biogas and natural gas. The functional unit is 1 MJ methane injected to the natural gas grid. Emissions weighted to impact categories are not presented for each step of the process (except for GWP). Impact assessment is made using EcoIndicator 1999.
5. Environmental assessment of biogas co- or tri-generation units by life cycle analysis methodology by Chevalier & Meunier (2005). The study comprises both biogas from crop residues and natural gas. The functional unit is 1 MJ of electricity and 1.6 MJ of heat or cold. Emissions are not presented for each step of the process. Impact assessment is made using EcoIndicator 1999.

The most useful study for a stepwise description of the environmental impact from the biogas process is number one in the list above. Studies 2 and 3 describe the whole life cycle for natural gas but with different functional units. It is not possible to find out how allocation between electricity and heat has been made, as the combustion facilities may include co-generation. This problem is further elaborated in the discussion. Study 4 is possible to use for a comparison of the total system using a pre combustion system boundary. Study 5 is possible to use for a comparison of the total system where methane is used for electricity and heat or cold. No study makes a comparison for vehicle fuel which is discussed later on.

### 2.3 Interpretation and improvement analysis

Interpretation and improvement analysis is made in the Results and conclusions section.

## 3. Life cycle assessment

Before going into detail of the different biogas production steps a general overview of the biogas system is presented.

Biogas is formed when microorganisms, especially bacteria, degrade organic material in the absence of oxygen. Production of biogas from the remains of dead plants and other organisms is a natural biological process in many ecosystems with a poor oxygen supply, for example in wetlands, rice paddies, lake sediments, and even in the stomachs of ruminating animals. (Swedish Biogas Association, 2004)

The large quantities of organic waste produced by modern society must be treated in some way before being recycled back to nature. Some examples of such organic wastes are sludges from municipal waste water treatment plants, kitchen refuse from households and restaurants, and waste water from the food processing industry. In a biogas process, the natural ability of microorganisms to degrade organic wastes is exploited to produce biogas and a nutrient rich residue which may be used as a fertiliser. The main constituent of biogas, methane, is rich in energy, and has a long history of use by mankind. (Swedish Biogas Association, 2004)

There are several technical solutions for how to recover biogas from organic residues, sewage water and biomass. What they have in common is that a sealed tank, a biogas reactor, is used for the anaerobic degradation of the material. If the gas is to be used as vehicle fuel carbon dioxide, hydrogen-sulphur compounds, ammonia, particles and moisture (steam) must be separated from the gas, making the gas to mainly consist of methane. (IVL, 1999)

Nowadays, production of heat and electricity is one of the major applications. As an environmentally-friendly alternative to diesel and petrol, biogas may also be refined to produce vehicle fuel. (Swedish Biogas Association, 2004)

Landfill gas cannot be used as vehicle fuel due to high concentration of nitrogen. The clean biogas is fuelled to the vehicle in a completely closed system by fast fuelling or slow fuelling. The gas station can be situated close to the production facility or be distributed by pipes or mobile gas tanks. (IVL, 1999)

The production system for biogas is depicted in Figure 4.



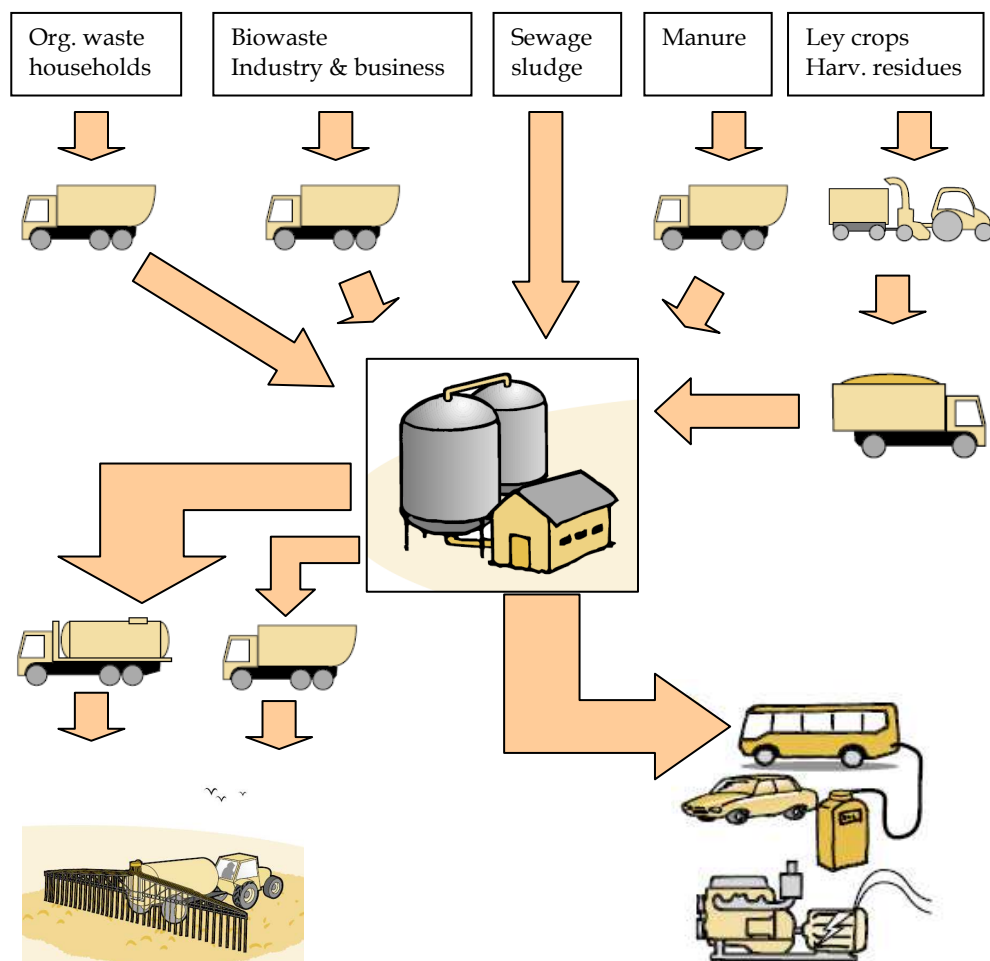


Fig. 4. Biogas system. Source: Eriksson & Hermansson, 2009

As a biogas plant is sealed there are very low losses of methane which does not just affect the energy efficiency but also contributes to global warming. Odour levels are normally lower than for open air composting and similar to reactor composting. The process, if made as wet digestion, uses fresh water for dilution but a large part of the process water is circulated to maintain the bacteria culture in the process. The digestate (the sludge which remains after digestion) is often dewatered leaving a dry digestate which can be used as fertiliser and a wet fraction which is normally sent to a wastewater treatment plant. Some electricity is used for pumping and mixing and heat is needed for hygienisation and heating of the material to the temperature inside the digester. Heat is supplied by a local gas boiler or district heating as to maximise the gas production. (Eriksson & Hermansson, 2009)

Despite energy use and some emissions, the major environmental benefit occurs when biogas substitutes fossil fuels. The digestate reduces the need for chemical fertiliser, but this effect is



normally of minor environmental importance. A problem is however that the use of organic fertiliser gives rise to some nutrient leaching compared to mineral fertiliser, in which a much larger share of the nitrogen is plant available which in turn leads to greater precision in fertilising. In a systems perspective, the alternative waste treatment is also of importance. The environmental benefit is larger if the alternative is composting than incineration with energy recovery, in particular if the plant is made as combined heat and power production. (Eriksson & Hermansson, 2009)

### 3.1 Raw material

The raw material (in thermal applications called the fuel) is called substrate. Biogas can be produced using one or more substrates. The main sources are:

- Municipal organic waste (food waste)
- Biowaste from industry and business activities (e.g. fat, waste from grocery stores, biosludge from pulp and paper industry, dairy by-products, rejected animal food, fishery by-products etc.)
- Raw sewage sludge (produced at wastewater treatment plants)
- Manure
- Harvest residues
- Ley crops

The latter three are more common in small to medium scale plants. Large-scale anaerobic digesters often use a variety of different substrates from one or more sources. What these substrates have in common is that the carbon is present in an easy degradable form (less lignin and cellulose and more carbohydrates, fat and starch) and therefore well suited for anaerobic digestion.

Biogas is also produced in landfill sites due to decomposition of organic material inside the landfill. To facilitate this, the landfill has to be equipped with a gas recovery system. The biogas produced is often more polluted than biogas from an anaerobic digester and therefore mostly used in gas engines or gas boilers for recovery of heat and/or electricity which can be used on site. Landfill gas is not further investigated here.

According to Börjesson & Berglund (2006) (Table 2) the corresponding emissions from this step are as presented in Table 2.

Per tonne raw material	Energy input	Emissions						
		CO <sub>2</sub> (kg)	CO (g)	NO <sub>x</sub> (g)	SO <sub>2</sub> (g)	HC (g)	CH <sub>4</sub> (g)	Particles (g)
Raw material	(MJ)							
Ley crops	440	31	24	270	36	17	9.8	9.9
Straw	230	16	23	150	6.6	11	0.057	2.3
Tops and leaves of sugar beet	100	7.2	7.6	78	4.8	4.7	0.057	1.3
Municipal organic waste	250	17	33	160	5.6	14	0.021	2.2

Table 2. Emissions from and energy input into the cultivation of different crops and collection of municipal organic waste. Source: Börjesson & Berglund, 2006

### 3.2 Technologies for thermal gasification

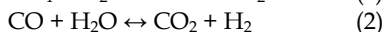
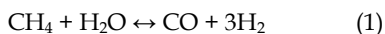
Methane gas can be produced from biomass by gasification. The gasification can be thermal or made by anaerobic digestion of easy degradable biomass. A short description on thermal gasification is presented below, but no LCA data have been included in the study as gasification of biomass is rare and still in a developing phase. The information refers to (SGC, 2008).

Gasification is a thermal process that breaks down the chemical bonds in the fuel in order to produce an energy rich gas. The process is an endothermic process which requires external heat. Gasification is divided into two steps; pyrolysis, which is a low temperature process that operates without any oxidation and gasification that needs a gasification agent that contains oxygen such as steam or air. (Bohnet, 2005)

During gasification, it is important to maintain the optimum oxygen input. The maximum efficiency of the gasification is achieved when just enough oxygen is added to allow complete gasification. If more oxygen is added, energy is released as sensible heat in the product stream. If biomass is heated to about 400°C pyrolysis will start to occur. The pyrolysis does not require any oxygen but only the volatile compounds in the biomass will be gasified. Biomass contains ca 60 % volatile compounds compared to coal which contains < 40 % volatile compounds. This makes biomass more reactive than coal. After thermal decomposition the volatile compounds are released as H<sub>2</sub>, CO, CO<sub>2</sub>, H<sub>2</sub>O, CH<sub>4</sub> etc which is also known as pyrolysis gas. The remains after the pyrolysis is char coal. (Bohnet, 2005)

The pyrolysis can not convert all of the biomass into volatile compounds and therefore gasification is required. The gasification requires much higher temperatures than pyrolysis, usually in the range of 800-900°C and with a gasification agent present. The gasification includes partial oxidation and it breaks down most of the feedstock into volatile compounds and the remaining nutrients like alkaline earth metals etc. end up as ash. The produced gas from the gasification contains synthesis gas or syngas which consists of carbon monoxide, CO and hydrogen, H<sub>2</sub>. The gas also contains methane, higher hydrocarbons like ethane, tars and inorganic impurities like HCl, NH<sub>3</sub>, H<sub>2</sub>S and CO<sub>2</sub>.

The product gas from the gasifier contains the volatile components from the pyrolysis as well as the syngas. The composition of the gas depends on a number of parameters such as gasification temperature and pressure, feedstock, reactor type and gasification agent. Generally higher temperature favours syngas production while lower temperature yields higher tar and methane rich gases. Increased pressure will increase the methane yield due to the equilibrium of reaction (1). (Bohnet, 2005)



Because of the endothermic reactions in gasification, heat must be added. This can be achieved either direct, with partial oxidation and/or combustion as in the case with air or pure oxygen as gasification medium or indirect. When air is used as gasification medium in direct gasification, the product gas is nitrogen diluted. This will decrease the lower heating

value, LHV, of the gas and increase the cost of the downstream processes as more gas needs to be processed. An alternative is to use pure oxygen as gasification medium. This will eliminate the nitrogen dilution problem but it increases the costs significantly.

### 3.3 Technologies for biogasification

There are in general two main types of anaerobic digestion, a wet technology where the substrate is diluted with water and a dry or semi-dry technology addressed for dry substrates. First the wet process will be presented, followed by a short description of the less used dry technology. The text refers to Eriksson & Hermansson, 2009.

The substrate enters the biogas plant in a reception hall. The waste is then taken to homogenisation (a mill or screw press) and then by screw transporters to a pulper. In the pulper the waste is mixed with hot water and steam to reach a temperature of 70 °C with DM 13 % making it a fluid possible to pump. Here hygienisation (pasteurisation) takes place (pathogenic organisms are being killed) during one hour under powerful stirring. Heavy material as stones, gravel and metal is removed from the bottom of the pulper.

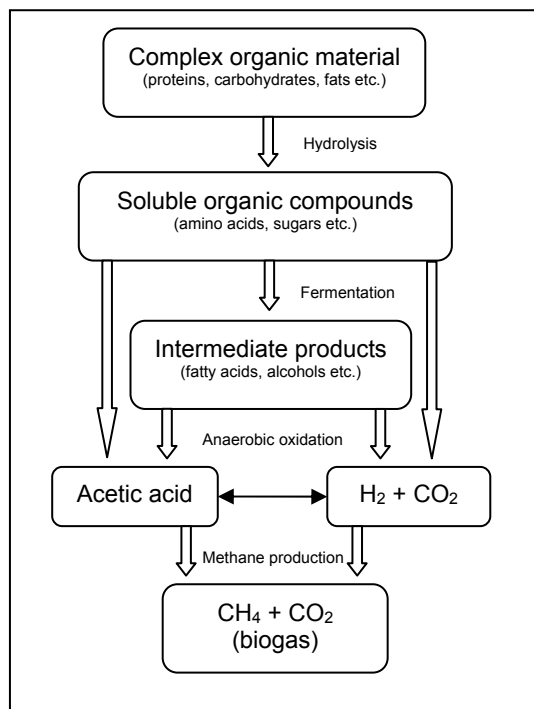


Fig. 5. Degradation process in anaerobic digestion.

Source: Swedish Biogas Association (2004)

After hygienisation the material is pumped to sand- and float filters where light materials as eg. plastic are removed from the surface and heavy material from the bottom. The mix is

now called raw sludge and can be compared to dewatered sewage sludge. The raw sludge is pumped to a raw sludge storage equipped with heat recovery and mixer. Reject material is transported to containers for further treatment like landfill and/or incineration.

From the raw sludge storage the sludge is pumped to the digestion chamber where the organic material is degraded due to the microbiological activity. The degradation process is described in Figure 5. There is a mixer in the digestion chamber in order to fulfil complete digestion. The hydraulic retention time and temperature varies between different plants. At temperatures 4-25 °C the process is psychrophilic which is very rare for large scale facilities. At 25-45 °C the process is mesophilic which is the most common process for anaerobic digestion of sewage sludge. Finally at 50-60 °C the process is thermophilic which is the most common process for anaerobic digestion of municipal organic waste. Biogas is released at the top of the digestion chamber and digested material is pumped to a covered digestate storage. Inside the storage some digestion will continue and biogas produced can be recovered.

Another process design is dry digestion. The difference between wet and dry digestion is the DM content in the digestion chamber. In wet digestion the DM is 2-10 w% while dry digestion works at 20-35 w%. Dry digestion should not be mistaken as wet composting as the final products are different. In Germany there are more than 300 plants for dry digestion. The most common method is batch-wise percolation bed in heated digestion reactors where the material is loaded and reloaded by tractors or wheel-loaders through a gas safe port at the short side of the reactor.

According to Börjesson & Berglund (2006) (Tables 3-4) the corresponding emissions from this step comes from transport of raw materials to a centralised biogas plant (Table 3) and plant operation (Table 4).

Per tonne of raw material	Energy input	Emissions						
		CO <sub>2</sub> (kg)	CO (g)	NO <sub>x</sub> (g)	SO <sub>2</sub> (g)	HC (g)	CH <sub>4</sub> (g)	Particles (g)
Raw material	(MJ)							
Ley crops, tops and leaves of sugar beet	11	0.77	0.14	7.1	0.25	0.41	< 0.01	0.12
Straw	29	2.0	0.38	19	0.65	1.1	< 0.01	0.31
Liquid manure	10	0.70	0.13	6.5	0.22	0.37	< 0.01	0.11
Food industry waste	16	1.1	0.21	10	0.36	0.60	< 0.01	0.17
Municipal organic waste	48	3.3	0.62	31	1.1	1.8	< 0.01	0.51

Table 3. Emissions from and energy input into the transport of raw materials to a centralised biogas plant. Source: Börjesson & Berglund, 2006

Note that figures in Table 4 represent a large-scale biogas plant. In Börjesson & Berglund, 2006 data for farm-scale plant is also displayed in Table 4 but have been left out here for space reasons. Large-scale plants have less energy input and less emissions except for electricity input and emissions of CO<sub>2</sub>. Electricity and CO<sub>2</sub> are linked to each other as the electricity is assumed to be based on natural gas.

Per tonne of raw material	Energy input		Emissions						
	Electr. (MJ)	Heat (MJ)	CO <sub>2</sub> (kg)	CO (g)	NO <sub>x</sub> (g)	SO <sub>2</sub> (g)	HC (g)	CH <sub>4</sub> (g)	Particles (g)
Raw material									
Ley crops	180	240	12	8.8	36	1.3	2.3	3.2	1.1
Straw	570	870	39	29	120	4.5	8.0	10	3.8
Tops and leaves of sugar beet	160	200	10	7.4	31	1.1	1.9	2.7	1.0
Liquid manure	53	85	3.6	2.7	11	0.4	0.8	1.0	0.4
Food industry waste	53	85	3.6	2.7	11	0.4	0.8	1.0	0.4
Municipal organic waste	230	320	15	11	46	1.7	3	4	1.5

Table 4. Emissions from and energy input into the operation of large-scale biogas plants. Source: Börjesson & Berglund, 2006

### 3.4 Distribution and use of solid residues

Besides biogas an organic fertiliser is also produced from anaerobic digestion. The digestate can to some extent replace chemical fertiliser and thereby contribute to lower costs and environmental impact. Compared to spreading of manure, methane emissions can be avoided. In a biogas plant the nitrogen is transformed to ammonia which is more easy accessible to the plants than nitrogen bound in organic compounds. Compared to direct use of manure, nitrogen leakage from agriculture can be substantially decreased causing an improved water quality in surrounding watercourses. In addition the digestion reduces odour and as mentioned before kills pathogens.

The digestate contains appr. 95 % water. In order to reduce transport work and problems in finding spreadable land area, the digestate is often dewatered to a water content of less than 70 %. This is performed with a centrifuge. The dry digestate can be stored in a digestate storage and then transported to satellite storages in close connection to the spreading areas. The reject water from the centrifuge contains considerable amounts of nitrogen (ammonia) and can be spread with liquid manure spreaders or diverted to a wastewater treatment plant. If the digestate cannot be used within agriculture it can be mixed with compost, peat and sand to form soil products to be used in gardening. (Eriksson & Hermansson, 2009)

There are also ongoing research which tests drying and pelletisation of the digestate. The pellets can then be used either as fuel or as fertiliser in agriculture or forestry. Pelletisation would mean energy use for drying and pelletisation but also energy savings for transport. Pellets are also easier to handle and store from one season to another. Nutrient pellets could also be more nutrient efficient than dry sludge, as the nitrogen is slower emitted leading to a higher uptake in plants. This is an area for further research and can be of interest in areas with low degree of agriculture.

According to Börjesson & Berglund (2006) (Table 5) the corresponding emissions from this step are as presented in Table 5. It is worth to notice that this study does "not consider potential changes in various emissions from arable soil (such as nitrous oxide, N<sub>2</sub>O, and am-

monia,  $\text{NH}_3$ ), leakage of nitrate ( $\text{NO}_3^-$ ), or methane emissions, due to changes in the handling of the raw materials.” (Börjesson & Berglund, 2006)

Per tonne of digestate	Energy input	Emissions						
Operation	(MJ)	$\text{CO}_2$ (kg)	CO (g)	$\text{NO}_x$ (g)	$\text{SO}_2$ (g)	HC (g)	$\text{CH}_4$ (g)	Particles (g)
Transport	16	1.1	0.21	10	0.36	0.60	< 0.01	0.17
Spreading	25	1.7	1.7	15	0.30	0.53	< 0.01	0.23

Table 5. Emissions from and energy input into transport and spreading of digestate.

Source: Börjesson & Berglund, 2006

### 3.5 Distribution and use of biogas

Biogas contains methane (appr. 60 %), carbon dioxide and minor amounts of hydrosulphurous. The gas can be combusted directly in a gas boiler for heat generation or in a gas engine for electricity generation (occasionally surplus heat is also recovered by water cooling). If the biogas is to be used in vehicles it must be upgraded, i.e. cleaned (removal of carbon dioxide and pollutants) and pressurised. (Eriksson & Hermansson, 2009)

Physical absorption (water wash) is the most commonly used method for upgrading biogas in Sweden. This method makes use of the fact that gases like carbon dioxide, hydrogen sulphide and ammonia are more readily dissolved in water than methane. The solubility of carbon dioxide increases with increasing pressure and decreasing temperature. (Swedish Biogas Association, 2004)

Pressure Swing Adsorption (PSA) is the second commonest method in use. PSA separates out carbon dioxide, oxygen, nitrogen and hydrogen sulphide, trapping molecules according to molecular size using, for example, activated carbon at different pressures. Hence, the method is sometimes called the ‘molecular sieve’ technique. (Swedish Biogas Association, 2004)

Absorption using Selexol is a method in which carbon dioxide, hydrogen sulphide and ammonia are absorbed by Selexol, a glycol solution. The method is based on the same principle as physical absorption with water. However, Selexol is more effective, since it absorbs three times more carbon dioxide. (Swedish Biogas Association, 2004)

Chemical absorption (chemisorption) uses a chemical to bind carbon dioxide. The advantage of this method is that the chemical only absorbs carbon dioxide and, if present, hydrogen sulphide, whereas virtually no methane is removed. This leads to a very high purity of the upgraded biogas, which contains about 99 % methane. (Swedish Biogas Association, 2004)

One alternative to the conventional technologies is to upgrade biogas with cryogenic technology, which means that the gas is chilled and the differences in condensation temperature for different compounds are used to separate impurities and  $\text{CO}_2$  from  $\text{CH}_4$ .  $\text{CO}_2$  condense at  $-78.5^\circ\text{C}$  at atmospheric pressure. The technology can be used to upgrade raw biogas by chilling it to the condensation temperature for  $\text{CO}_2$  or it can be further chilled to  $-161^\circ\text{C}$

(condensation temperature for  $\text{CH}_4$  at atmospheric pressure) to produce liquid biogas, LBG. It is more energy intensive to chill the gas to  $-161^\circ\text{C}$  but in some situations it results in a more valuable product since LBG is more than 600 times space efficient compared to biogas in its gas phase at atmospheric pressure (around 3 times more space efficient compared to compressed biogas, 200 bar). This makes the biogas available for more customers since the produced LBG can be transported on road in vacuum insulated semi-trailers to remote fuel stations. On a multi-purpose fuel station it is then stored as LBG and fuelled as either LBG or CBG (compressed biogas, 200 bar). LBG can also be produced using one of the conventional upgrading technologies connected with a small-scale liquefaction plant. This small-scale liquefaction plants are either a closed nitrogen cycle or a closed mixed refrigerant cycle. The first has a low efficiency but it is not as complex as the latter since it only use one refrigerant (nitrogen). (Johansson, 2008)

When using cryogenic upgrading technology clean, liquid  $\text{CO}_2$ ,  $\text{LCO}_2$ , comes as a by-product. This  $\text{LCO}_2$  could be used in external processes replacing fossil energy and bring in extra income to the biogas production plant. Two possible applications are cryogenic temperature control and fertilizing of greenhouses. The  $\text{LCO}_2$  probably has to be sold directly to the user, and the possibility to get an income from this product is also very site specific. An interesting alternative could be to place a greenhouse close to a biogas production and upgrading plant. In this way the greenhouse could get an organic fertilizer from the digester chamber and heat and  $\text{CO}_2$  from the upgrading process. (Johansson, 2008)

The distribution of biogas can also be facilitated by injection to the natural gas grid. The establishment of natural gas grids is therefore very important as it makes the introduction of biogas in the society easier. The economy of biogas production does not allow such heavy investments as gas grids, nor can the delivery safety be high enough. Biogas is a local energy source, whereas natural gas is a transnational energy source.

According to Börjesson & Berglund (2006) (Table 6) the corresponding emissions from this step are as presented in Table 6. The figures for upgrading of biogas have been calculated by subtracting the figures including upgrading from the figures without upgrading.

Per MJ of biogas	Energy input	Emissions						
		$\text{CO}_2$	CO	$\text{NO}_x$	$\text{SO}_2$	HC	$\text{CH}_4$	Particles
	(MJ)	(g)	(mg)	(mg)	(mg)	(mg)	(mg)	(mg)
Raw material								
Ley crops	0.11	6.0	3.0	20	0.0	0.4	1.30	0.3
Straw	0.11	6.0	3.0	12	0.2	0.4	1.30	0.3
Tops and leaves of sugar beet	0.11	6.0	2.7	12	0.2	0.4	1.30	0.3
Liquid manure	0.11	6.0	3.2	12	0.2	0.4	1.30	0.3
Food industry waste	0.11	5.6	3.0	12	0.2	0.4	1.33	0.3
Municipal organic waste	0.11	6.0	3.0	12	0.2	0.4	1.30	0.3

Table 6. Emissions from and energy input into upgrading of biogas to vehicle fuel.

Source: Börjesson & Berglund, 2006



#### 4. Results and conclusions

In Table 7 the life cycle inventory from the different steps have been added up to cover the whole biogas system.

Per MJ of biogas	Energy input	Emissions						
	(MJ)	CO <sub>2</sub> (g)	CO (mg)	NO <sub>x</sub> (mg)	SO <sub>2</sub> (mg)	HC (mg)	CH <sub>4</sub> (mg)	Particles (mg)
Raw material								
Ley crops	0.40	21	15	150	16	9.2	5.3	5.0
Straw	0.35	14	12	85	2.9	5.0	1.8	1.7
Tops and leaves of sugar beet	0.27	12	9.3	81	3.7	4.5	1.4	1.6
Liquid manure	0.31	11	7.8	63	1.9	3.3	1.8	1.3
Food industry waste	0.15	5.4	3.5	33	1.0	1.8	0.77	0.67
Municipal organic waste	0.26	12	14	85	2.8	6.1	1.1	1.5

Table 7. Summary of the emissions and energy input in production of biogas in large-scale plant. Source: Börjesson & Berglund, 2006

Even if this is not a complete life cycle inventory it reveals large differences for different substrates. As mentioned above, large-scale or farm-scale plant design also have an influence on the result, as well as choice of system boundaries, electricity generation etc. We will come back to such crucial factors for both biogas and natural gas.

This result now has to be compared to corresponding figures for natural gas. From (IVL, 1999) it was possible to extract figures similar to Table 7. In Table 8 pre combustion as well as different gas applications are presented.

Per MJ of natural gas	Energy input	Emissions						
	(MJ)	CO <sub>2</sub> (g)	CO (mg)	NO <sub>x</sub> (mg)	SO <sub>2</sub> (mg)	NMVOC (mg)	CH <sub>4</sub> (mg)	Particles (mg)
Step in fuel cycle								
Production and distribution	0.047	3.09	3.01	12.7	0.23	1.53	2.8	0.022
Combined cycle	0.001	57	11	11	0.6	0.46	2.0	0.096
Heat station	-	56	10	49	0	1	0.1	-
Power station	-	56	10	58	0	1	0.1	-
Residential service	-	56	10	10	0	1	0.1	-
Light-duty vehicles	-	52	35	28	-	35	-	1.8
Heavy-duty vehicles	-	52	1.7	170	-	4.2	38	1.7

Table 8. Summary of the emissions and energy input in production, distribution and use of natural gas. Source: IVL, 1999

When comparing tables 7 and 8 it is obvious that the pre combustion figures are much lower for natural gas (row 1 "Production and distribution" in Table 8) than for biogas regardless of raw material. For the different gas use applications, emissions of CO<sub>2</sub> are almost the same for all alternatives, whereas the other emissions may vary considerably.

As mentioned earlier it is not easy to find a similar study consistent with Börjesson & Berglund, 2006. The same authors have reported a continued assessment in Börjesson & Berglund, 2007. In the complex assessment three functional units are defined: 1 MJ of heat, 1 MJ of heat and power and 1 MJ of kinetic energy (to reflect vehicle fuel). In fact the assessment also includes functional unit plant nutrients as N and P (this is compensated for by chemical fertiliser) even if this is not put out in words or figures. The system enlargement considers conventional alternatives both for raw material input and energy service output of the biogas system. This means that indirect environmental impact is included. Electricity is assumed to be natural gas in condensing plants, heat comes from fuel oil combustion and petrol and diesel are used for additional transport in light-duty and heavy-duty vehicles. There are also a number of assumptions for alternative waste handling (composting) and cropping systems. The impact assessment includes global warming potential (GWP), acidification potential (AP), eutrophication potential (EP) and photochemical oxidant creation potential (POCP).

This study is, in my eyes, how a proper comparison should be carried out, taking into account primary and secondary upstream and downstream effects of biogas systems. As all energy alternatives are from fossil fuels the biogas system comes out as the least polluting one for all functional units, independent on large-scale or small-scale plants. This is however not a comparison of biogas and natural gas.

From the method section we learned that studies 4 and 5 could be used for pre combustion or total system comparisons. Both studies present results in impact categories using EcoIndicator99. In study 5 the LCI has been weighted with the CML method and EcoIndicator has been used for valuation.

Study 4 (Jury et al, 2010) shows pre combustion results where biogas has a higher impact than natural gas for human health and ecosystem quality. However, for climate change, resources and cumulative energy and exergy demand, the results are opposite. Land occupation and use of fertiliser are used as explanation for this outcome. To produce 1 MJ of biogas about 2.5 MJ energy resources are consumed, whereas natural gas is more efficient with just above 1 MJ. But the non-renewable part is lower for biogas; 0.5 MJ/ MJ in relation to 100 % non-renewable for natural gas.

In study 5 (Chevalier & Meunier, 2005) biogas co- and trigeneration are compared to conventional heat/cold and power production. The conventional generation of heat is from natural gas industrial furnace, cold from vapour compression chiller using electricity and finally electricity from the grid in Germany, Austria and France. Biogas co-generation is by far better than the conventional alternatives and biogas tri-generation is somewhat worse than the French setup, but better than all the rest.

From Riva et al (2006) it is obvious that the environmental performance for natural gas is different depending on country of origin and of course energy conversion technology. In Table 9 the emissions in g/kWh el for natural gas used in Italy are presented. Significant differences between the different alternatives are observed for all emissions.

g/kWh el	ETH Russia	ETH Netherl.	BUWAL	Legislation Steam plant	Legislation Combined Cycle	Gas Russia	Gas Italy
NO <sub>x</sub>	1.24	0.88	1.49	0.96	0.61	0.39	0.34
SO <sub>2</sub>	0.35	0.009	0.27	0.33	0.22	0.04	0.007
CO <sub>2</sub>	742	644	767	635	427	383	356
CH <sub>4</sub>	4.07	0.46	1.76	3.87	2.6	1.39	0.17

Table 9. Emissions of natural gas cycle for electricity production. ETH refers to EcoInvent database, BUWAL corresponds to a Western Europe scenario, steam plant and combined cycle use gas from Russia and gas from Russia and Italy are used in a combined cycle. Source: Riva et al, 2006

So, what have we learned from this? From present studies it is possible to make a list of crucial factors or parameters that influence the result.

- From what raw materials are the biogas made of?
- What is the size of the biogas plant, farm-scale or large-scale?
- Which is the alternative use of the raw materials?
- Which is the alternative use of the biogas?
- Are the emissions from use of digestate included and how?
- How are the emissions from the biogas system allocated between digestate and biogas?
- What is the country of origin for natural gas and where is it used?
- What energy conversion technology (heat and/or power) has been applied for the bio/natural gas?
- Is the biogas used in light-duty vehicles substituting petrol or heavy-duty vehicles (busses) substituting diesel oil?
- From what type of driving cycle has the emission factors for vehicles been taken?

These are all crucial factors in the inventory. It is also a fact that the results for CO<sub>2</sub> can point in one direction, but if other impact categories are also included the picture can change. Problems with allocation like heat only (Dinca et al, 2006) or electricity only (Riva et al, 2006) in cogeneration plants has also been identified as an important factor that may influence the results. Some of the papers mentioned above include a variety of sensitivity analyses, such as transport distance from field to biogas plant, as a method to pinpoint these uncertainties. A more thorough comparison of the different studies would probably reveal even more potential key parameters. However it has not been in the scope of this study to perform such a review.

## 5. Future research

There is definitely a need for a best practice when it comes to LCA of fuels. Life cycle inventories are available in different software as GaBi, Umberto and SimaPro but it takes a great deal of knowledge to grasp what is included and not and what underlying assumptions have been made. There is a risk that biogas, as well as LCA, get negative attention when one supplier of biogas cars states that the emission factor is 22 g CO<sub>2</sub>/km at the same time as different websites tells the consumer that the emission factor is 124 g CO<sub>2</sub>/km. To common people it is unbelievable that the conclusions can differ that much for the same fuel. A similar discussion is found for bioethanol. How to handle land use issues can be of particular interest as these circumstances has an impact on LCA results and is also an ethical aspect as to whether agricultural fields should be used for food production or for energy purposes. Now famine is much more of a logistic and socio- economic problem, but in a short-term scenario food production may be replaced by energy crops on the margin.

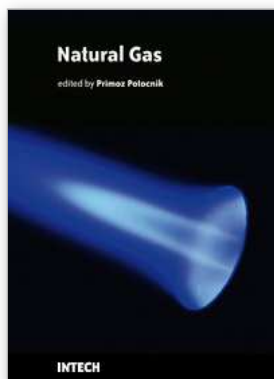
One particular aspect of best practice is to whether gas production and gas use should be separated or not. What is shown above is that it is hard to separate them in a consistent manner. One idea, which is not always used, is to declare emissions or impact from each step, or at least pre combustion and different alternatives for post combustion. It should then be possible to add one or more steps to each other to get the total picture.

In a broader context more research is needed to analyse and optimize both biogasification and thermal gasification. Fiber sludge from pulp and paper industry is a potential substrate that may enter the market if technology and economy allows it.

## 6. References

- AvfallSverige (2008) Energi från avfall ur ett internationellt perspektiv (Energy from waste in an international perspective), report 2008:13, ISSN 1103-4092
- BFE (2006) Schweizerische Statistik der erneuerbaren Energien –Ausgabe 2005, Bundesamt für Energie
- Bohnet, B. (2005) Ullmann's Encyclopedia of Industrial Chemistry, 7<sup>th</sup> edition, Wiley-VCH
- Börjesson, P. & Berglund, M. (2007) Environmental systems analysis of biogas systems – Part II: The environmental impact of replacing various reference systems, *Biomass and Bioenergy* 31 (2007) 326-344
- Börjesson, P. & Berglund, M. (2006) Environmental systems analysis of biogas systems – Part I: Fuel-cycle emissions, *Biomass and Bioenergy* 30 (2006) 469-485
- Chevalier, C. & Meunier, F. (2005) Environmental assessment of biogas co- or tri-generation units by life cycle analysis methodology, *Applied Thermal Engineering* 25 (2005) 3025-3041
- Dinca, C., Rousseaux, P & Badea, A. (2006) A life cycle impact of the natural gas used in the energy sector in Romania, *Journal of Cleaner Production* 15 (2007) 1451-1462
- Energimyndigheten (2007) Produktion och användning av biogas 2005 (Production and use of biogas in 2005), ER2007:05; ISSN 1403-1892
- Energinet (2005) Gaskvalitet årsgennomsnitt (Gas quality, annual averages) 2005, <http://www.energinet.dk>
- Eriksson, O. & Hermansson, T. (2009) Biogas i Gästrikeregionen – en systemanalys (Biogas in the Gästrikeregion – a systems analysis)

- Eriksson, O., Finnveden, G., Ekvall, T. & Björklund, A. (2007) Life Cycle Assessment of fuels for district heating – A comparison of waste incineration, biomass- and natural gas combustion, *Energy Policy* 35 (2007) 1346-1362
- Euroobserver (2009) The state of renewable energies in Europe - 2009 edition, ISSN 2101-9622
- Euroobserver (2008) Biogas barometer, SYSTÈMES SOLAIRES le journal des énergies renouvelables N° 186
- Euroobserver (2007) Biogas barometer, SYSTÈMES SOLAIRES le journal des énergies renouvelables N° 179
- IVL (1999) Miljöfaktabok för bränslen Del 2 Bakgrundsinformation och Teknisk bilaga (Environmental fuel handbook Part 2 Background information and Technical appendix), B 1334 B, Stockholm, Sweden
- Johansson, N. (2008) Production of liquid biogas, LBG, with cryogenic and conventional upgrading technology, - Description of systems and evaluations of energy balances, Master Thesis, Department of Technology and Society, Environmental and Energy Systems Studies, Lund university, ISRN LUTFD2/TFEM--08/5032--SE + (1-92)
- Jury, C., Benetto, E., Koster, D., Schmitt, B. & Welfring, J. (2010) Life Cycle Assessment of biogas production by monofermentation of energy crops and injection to the natural gas grid, *Biomass and Bioenergy* 34 (2010) 54-66
- Riva, A., D'Angelosante, S. & Trebeschi, C. (2006) Natural gas and the environmental results of life cycle assessment, *Energy* 31 (2006) 138-148
- SGC (2008) Substitute natural gas from biomass gasification, Swedish Gas Centre, report SGC 187, 1102-7371, ISRN SGC-R-187-SE
- SGC (2007) Biogas - basic data on biogas – Sweden, Swedish Gas Centre, brochure
- SGC (2005) Energigas och miljö (Energy gases and the environment), Swedish Gas Centre
- Swedish Biogas Association (2004) Biogas – renewable energy from organic waste, brochure



## **Natural Gas**

Edited by Primoz Potocnik

ISBN 978-953-307-112-1

Hard cover, 606 pages

**Publisher** Sciyo

**Published online** 18, August, 2010

**Published in print edition** August, 2010

The contributions in this book present an overview of cutting edge research on natural gas which is a vital component of world's supply of energy. Natural gas is a combustible mixture of hydrocarbon gases, primarily methane but also heavier gaseous hydrocarbons such as ethane, propane and butane. Unlike other fossil fuels, natural gas is clean burning and emits lower levels of potentially harmful by-products into the air. Therefore, it is considered as one of the cleanest, safest, and most useful of all energy sources applied in variety of residential, commercial and industrial fields. The book is organized in 25 chapters that cover various aspects of natural gas research: technology, applications, forecasting, numerical simulations, transport and risk assessment.

### **How to reference**

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Ola Eriksson (2010). Environmental Technology Assessment of Natural Gas Compared to Biogas, Natural Gas, Primoz Potocnik (Ed.), ISBN: 978-953-307-112-1, InTech, Available from:

<http://www.intechopen.com/books/natural-gas/environmental-technology-assessment-of-natural-gas-compared-to-biogas>

**INTeCH**  
open science | open minds

### **InTech Europe**

University Campus STeP Ri  
Slavka Krautzeka 83/A  
51000 Rijeka, Croatia  
Phone: +385 (51) 770 447  
Fax: +385 (51) 686 166  
[www.intechopen.com](http://www.intechopen.com)

### **InTech China**

Unit 405, Office Block, Hotel Equatorial Shanghai  
No.65, Yan An Road (West), Shanghai, 200040, China  
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元  
Phone: +86-21-62489820  
Fax: +86-21-62489821

© 2010 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the [Creative Commons Attribution-NonCommercial-ShareAlike-3.0 License](#), which permits use, distribution and reproduction for non-commercial purposes, provided the original is properly cited and derivative works building on this content are distributed under the same license.